National Aeronautics
and Space Administration

September 4, 1998
AO 98-OSS-06

Announcement of Opportunity

MUSES-C Science Team

Notice of Intent Due: **October 5, 1998**
Proposals Due: **November 20, 1998**

OMB Approval No. 2700-0085

MUSES-C Science Team

Announcement of Opportunity
Soliciting Proposals
for Basic Research in Space Science

AO 98-OSS-06
Issued: September 4, 1998

Office of Space Science
National Aeronautics and Space Administration
Washington, DC 20546-0001

MUSES-C Science Team
Announcement of Opportunity

Table of Contents

Announcement of Opportunity

MUSES-C Science Team

1. Description of Opportunity

1.1 Introduction

The National Aeronautics and Space Administration's (NASA) Office of Space Science (OSS) announces the opportunity to conduct scientific investigations as part of the U.S./Japanese Mu Space Engineering Spacecraft-C (MUSES-C) collaboration. Japan's Institute of Space and Astronautical Sciences (ISAS) is developing the MUSES-C spacecraft (Orbiter) while NASA's Jet Propulsion Laboratory (JPL) is developing the Rover. The Orbiter will perform remote sensing investigations of the asteroid and collect samples of the surface for return to Earth, while the Rover will be deployed on the asteroid to perform complementary investigations. The Rover will not return to Earth.

Although the primary role of the MUSES-C collaboration is to enable future science missions by validating new technologies in actual flight, this validation mission also offers opportunities to collect valuable science data at a near-Earth asteroid, currently planned to be 4660 Nereus. The primary scientific objectives of this MUSES-C collaboration are: 1) to determine an asteroid's surface morphology, the processes that affect its surface, its internal structure, its mineralogical and elemental composition, and its relationship to meteorites; 2) to characterize an asteroid's size, shape, mass, bulk density, spin state, as well as its color and albedo properties; and 3) to characterize the surface soil properties, the nature and location of fractures, and the processes that affect an asteroid's surface layer. This Announcement of Opportunity (AO) solicits proposals for individual investigators to conduct scientific research as members of the Joint Science Team for the MUSES-C collaboration using data from the Orbiter and Rover and from the returned samples.

NASA will accept proposals for scientific investigations based on any of the seven following sources of data. Proposals must refer to just one source of data from the list below; the Joint Science Team will develop investigations that require more than one source of data.

1) Orbiter Light Detection and Ranging (LIDAR);
2) Orbiter Asteroid Multiband Imaging Camera;
3) Orbiter Near-Infrared Spectrometer;
4) Rover Imaging Camera;
5) Rover Infrared Spectrometer;
6) Rover Alpha/X-ray Spectrometer; and
7) Samples of Nereus Returned to Earth by the MUSES-C Spacecraft.

NASA also expects selected investigators to participate on small, instrument-centered investigation teams either as Team Leader or Team Member, as given in Table 1 below.

The instruments are all facility instruments provided by ISAS and NASA. ISAS also plans to include an X-ray Spectrometer instrument as part of the Orbiter payload, but no U.S. investigations are being sought for collaboration on that instrument. Appendix C contains a description of the instruments and the mission, subject to the caveats given in Section 2.2 of this AO. Pending the submission of appropriate proposals of merit, NASA intends to select one of each type of investigation as listed above.

A Japanese M-V vehicle will launch the MUSES-C mission in January 2002, and the mission will arrive at Nereus in April 2003. The Orbiter will conduct detailed observations of the asteroid from a distance of less than about 20 km for approximately two months from April through May 2003. During this time, the Orbiter will descend toward Nereus up to three times, collecting a surface sample each time. The Orbiter will drop the Rover onto the asteroid during the first sampling opportunity, roughly five weeks after Nereus arrival, where the Rover may survive for the duration of Orbiter's encounter with the asteroid (approximately three weeks). NASA and ISAS do not plan to gather any scientific data from the Orbiter or Rover before Nereus arrival or after Nereus departure. Although the MUSES-C Project has identified a backup target, proposers should assume that the target will be Nereus.

Since this program is based on a bilateral agreement between NASA and ISAS, this AO is open only to organizations in the U.S. as well as to nonaffiliated members of the resident U.S. scientific community. As part of the joint NASA/ISAS arrangements in preparing this AO, NASA will only accept proposals having single Principal Investigators; NASA will reject proposals offering a team of Co-Investigators. All categories of U.S. organizations are welcome to participate: educational institutions, profit and nonprofit organizations, NASA Centers, and other U.S. Government agencies.

1.2 Formation of the Joint Science Team

Investigators selected as a result of this Announcement will serve on the Joint Science Team for the MUSES-C collaboration along with the ISAS and NASA Project Scientists and others as may be designated by ISAS and NASA. Note that just as NASA is choosing U.S. scientists to conduct investigations using instruments provided by ISAS, likewise ISAS is choosing Japanese scientists to conduct investigations using instruments provided by NASA. Table 1 presents the planned membership of the MUSES-C Joint Science Team.

Table 1: Membership in MUSES-C Joint Science Team

	NASA Personnel	Japanese Personnel
Orbiter Camera	Instrument Team Member	Instrument Team Leader
Orbiter LIDAR	Instrument Team Member	Instrument Team Leader
Orbiter IR Spectrometer	Instrument Team Member	Instrument Team Leader
Sample Science	Instrument Team Member	Instrument Team Leader
Orbiter X-ray Spectrometer		Instrument Team Leader and Instrument Team Member
ISAS Project Scientist		Joint Science Team Co-Chair
Rover Camera	Instrument Team Leader	Instrument Team Member
Rover IR Spectrometer	Instrument Team Leader	Instrument Team Member
Rover Alpha/X-ray Spectrometer	Instrument Team Leader	Instrument Team Member
NASA Project Scientist	Joint Science Team Co-Chair	

ISAS will select the Japanese members of the Joint Science Team through a process separate from this NASA AO.

This Joint Science Team plays a vital role in the MUSES-C collaboration by helping to maximize the mission science return, interacting with the planetary science community, and furthering the understanding of asteroids. The Joint Science Team will meet regularly throughout the lifetime of the Project and work with the Project Scientists and Managers to fulfill the collaboration's objectives. Toward this end, the NASA-selected members of the Joint Science Team are expected to:

- Provide science input for mission planning;
- Provide science input for resolving conflicts among requirements;
- Determine general data usage;
- Assist in instrument calibrations;
- Reduce and validate scientific data;
- Prepare reduced data for archiving in the Planetary Data System;
- Participate in Education/Public Outreach activities;
- Analyze, interpret, and publish findings in the peer-reviewed literature; and
- Support liaison efforts between the MUSES-C collaboration and the scientific community.

1.3 Schedule

Announcement of Opportunity release......................................September 4, 1998
Notice of Intent to propose due...October 5, 1998
Proposal submittal due by 5:00 pm CST..................................November 20, 1998
Selections (target)..February 1999
Award of funding (target)..April 1999

1.4 Relationship to Other Opportunities

NASA anticipates that after asteroid samples are returned to Earth, a NASA Research Announcement will be issued to solicit additional investigations for analysis of a portion of the samples. Other scientific data from the mission will also eventually be available in NASA's Planetary Data System archive for research through other programs.

2. Program Constraints, Requirements, and Guidelines

2.1 General Program Constraints and Guidelines

As part of an agreement reached with ISAS for this collaborative program, NASA is seeking proposals having only a single investigator, not a team of scientists. As a result, proposals must identify a single investigator, designated as the Principal Investigator, and may not have Co-Investigators. Proposals that do not meet this requirement will be rejected during NASA's compliance check and returned.

NASA anticipates selecting up to seven investigations from among the proposals submitted in response to this AO. As part of the investigations, NASA expects investigators to participate on the Joint Science Team, which will provide scientific guidance for instrument development, mission planning, mission operations, instrument calibration, and data archiving.

Investigators should plan to travel at least once per year to the Jet Propulsion Laboratory and once per year to ISAS during mission development. Investigators should also plan to be in residence at ISAS for the period of the encounter. Because all the samples will remain in Japan for the first year after their return from the asteroid, the investigator for the samples should plan to make his or her analyses in facilities in Japan. NASA has provided for an increase in program funding for the sample science investigation in the year the scientist is likely to spend in Japan. See Table 2 below.

2.2 Caveats and Baseline for Preparing Proposals

Although the MUSES-C collaboration may choose to send MUSES-C to another near-Earth asteroid, proposals should describe investigations for a MUSES-C mission specifically to 4660 Nereus.

Also, because of advanced technology, some of the instruments have relatively high risk in their development. As a result, proposers should be aware that the instruments on the Orbiter and Rover may be significantly modified during development. NASA or ISAS may even cancel one or more instruments if problems make this necessary. Nonetheless, proposers should base their proposed investigations on the descriptions of the instruments given in Appendix C of this AO.

2.3 Science Requirements

The relationship between the proposed scientific objectives, the data required to achieve those objectives, and the mission operations needed to obtain those data must be unambiguous and clearly stated in the proposal.

Recognizing that the choice of filters is fundamental to the investigation using data from the Rover Imaging Camera, proposers planning to use this facility instrument must also specify six filters, in addition to a clear filter, that they will need to conduct their investigation. The proposers should make clear how that specific choice of filters will allow them to conduct their investigation. The JPL MUSES-C-NASA Project will provide the filters; approximately $2K per filter has been allocated.

2.4 General Rules for Data Rights, Use, and Publication

The scientific community at large will have access to the MUSES-C science data following a period of calibration and validation of science data from each instrument. The ISAS MUSES-C Project will maintain the data records for both the Orbiter and Rover instruments in the project computer located in Japan. Throughout the data acquisition, calibration, and validation period, members of the Joint Science Team will be responsible for maintaining raw data, reduced data, calibrated data, validated data, and intermediate data products on this project computer. The MUSES-C collaboration expects that Team Leaders will make every effort to ensure that their Team Members have ready access to the necessary data and information so that these Team Members can successfully fulfill their responsibilities and meet the objectives of their proposed scientific investigations. If necessary, Team Leaders can authorize the export of data from the Project computer to computers at the Team Member's home institution.

The following rules apply to rights, use, and publication of data specifically from NASA's Rover:

1) There is no proprietary period for any data collected by Rover instruments;
2) Much of the data will be released early as Public Information Office releases and postings on the World Wide Web;
3) Science instrument data are subject to a validation period of no more than six months from the time of acquisition to allow its calibration and formatting. After calibration and formatting, the data will be deposited in NASA's Planetary Data System for access by the scientific community;
4) Data deposited with the Planetary Data System will contain the appropriate calibration information and ancillary data that will be updated throughout the period of investigation; and
5) NASA expects that all U.S. investigators selected through this AO will publish their results in a timely manner in the open scientific literature.

ISAS and NASA will jointly determine the rules on the rights, use, and publication of data from the Orbiter and from the samples. The Joint Science Team will resolve conflicts and problems involving the provision and use of data, or, if necessary, the NASA Program Scientist and his counterpart in ISAS will jointly resolve the issues.

2.5 Education/Public Outreach Requirement

OSS has developed a comprehensive approach for making education at all levels (with a particular emphasis on precollege education) and the enhancement of public understanding of space science integral parts of all of its missions and research programs. The two key documents that establish the basic policies and guide all OSS Education and Outreach activities are a strategic plan entitled *Partners in Education: A Strategy for Integrating Education and Public Outreach Into NASA's Space Science Programs* (March 1995), and an accompanying implementation plan entitled *Implementing the Office of Space Science (OSS) Education/Public Outreach Strategy* (1996). Both can be accessed by selecting "Education and Outreach" from the menu on the OSS homepage at URL <http://www.hq.nasa.gov/office/oss>, or from Dr. Jeffrey Rosendhal, Office of Space Science, Code S, NASA Headquarters, Washington, DC 20546-0001, USA.

In accord with these established OSS policies, up to 2% of the NASA budget for MUSES-C collaboration will be allocated to education and outreach. Because of the limited scope of this program, NASA does not expect a stand-alone Education/Public Outreach proposal component to be submitted with each research proposal. NASA does, however, expect that selected, NASA-funded investigators will become involved in and support a common MUSES-C Education/Public Outreach program to be defined and implemented in conjunction with the MUSES-C Project Office at JPL. Therefore, selected investigators should be prepared to spend up to about 5% of their time supporting such activities, which may include, but not be limited to, coming up with ideas for creative and worthwhile educational materials; preparing written background information suitable for primary and secondary school educational resources; and preparing portions of the MUSES-C data for use in educational and public outreach materials.

2.6 Schedule and Cost Requirements

2.6.1. Schedule Requirements

Proposals should specify periods of performance extending from the expected selection date through September 2004 for investigations using Orbiter or Rover instruments, and through September 2006 for investigations using the samples. All proposals must include separate budgets for each year.

2.6.2. Limitations on Funding

NASA has only a limited amount of funding for the selected investigations. During the compliance check, NASA will examine the budgets of all proposals to make sure they fit within the limitations given in Table 2. NASA will return without review any proposal that exceeds the limit in any fiscal year.

Table 2: Budget Limit per Investigation in Real Year $K

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06
Sample Analysis	16	18	18	31	40	30	25	308*
Other investigations	16	18	18	43	69	54	0	0

* NASA intends that the budget limit increase for Sample Analysis in Fiscal Year 2006 should allow a year of residency in Japan for analysis of sample material with the Japanese Sample Science Team.

2.6.3. Full Cost Accounting

If a proposal offers NASA-provided services, the proposed budget must include the full cost of Civil Service labor and NASA Center infrastructure support. If NASA guidance for full cost accounting has not been fully developed by the closing date for proposal submission, NASA Centers should submit cost proposals based on the instructions in the NASA Financial Management Manual, Section 9091-5, “Cost Principles for Reimbursable Agreements,” or based on their own, Center-approved, full-cost accounting models. Other Federal Government elements of proposals must follow their agency cost accounting standards for full cost. If no standards are in effect, the proposers must then follow the Managerial Cost Accounting Standards for the Federal Government as recommended by the Federal Accounting Standards Advisory Board.

2.7 International Participation

In response to this AO, NASA will only accept proposals from U.S. institutions in behalf of its resident staff or from nonaffiliated members of the resident U.S. scientific community.

2.8 Reference for Further Information

Questions about this AO may be directed to the NASA MUSES-C Program Scientist:

> Dr. Thomas Morgan
> Research Program Management Division
> NASA Headquarters
> Washington DC 20546
> Telephone: (202) 358-0828
> E-mail: Thomas.Morgan@hq.NASA.gov

3. Proposal submission information

3.1 Notice of Intent to Propose

NASA strongly encourages that all prospective proposers submit a Notice of Intent in accordance with the schedule in Section 1.3. Proposers must prepare this Notice of Intent in English and submit it electronically using the form found at Internet URL <http://cass.jsc.nasa.gov/panel/>. Anyone experiencing difficulty with this process should call the Lunar and Planetary Institute for assistance at (281) 486-2156 or (281) 486-2166.

To the extent that the proposer knows the following information by the due date, the Notice of Intent should include:

(a) Name, institutional address, telephone number, E-mail address, and fax number of the Principal Investigator, and

(b) Title of the proposed investigation, an indication of which type of investigation it will be (see Section 1.1), and a brief statement of the scientific objectives.

3.2 Format and Content of Proposals

Appendix A contains general NASA guidance for proposals, and NASA considers this guidance binding unless specifically amended in this AO. In order to facilitate evaluation, NASA also requires a uniform proposal format, described in Appendix B, for all proposals submitted in response to this AO. Failure to follow this outline may result in reduced ratings during the evaluation process, or in extreme cases, could lead to rejection of the proposal without review.

3.2.1. Certification

An official of the PI's institution who is authorized to certify institutional support and sponsorship of the investigation, as well as the management and financial parts of the proposal, must sign the proposal.

3.2.2. Quantity

Proposers must provide 20 copies of their proposal, plus the original signed proposal.

3.2.3. Submittal Address

Proposals must be delivered to:

MUSES-C Program
Lunar and Planetary Institute
3600 Bay Area Blvd.
Houston, TX 77058
(Delivery phone: 281-486-2166)

3.2.4. Deadline

The organization at the address above must receive all proposals by 5:00 pm, Central Time, by the closing date specified in Section 1.3. NASA will treat all proposals received after the closing date in accordance with NASA's provisions for late proposals (Appendix A, Section VII).

3.2.5. Notification of Receipt

NASA will notify the proposers in writing that their proposals have been received. Proposers not receiving this confirmation within two weeks after submittal of their proposals should contact the address given in Section 3.2.3.

4. Proposal evaluation and Selection

4.1 Evaluation and Selection Process

NASA will subject all proposals submitted in response to this AO to a preliminary screening that will determine their compliance to the constraints, requirements, and guidelines of the AO. Proposals not in compliance will be rejected without further review and returned.

NASA will consider proposals offering any of the following to be noncompliant:

- Flight instrumentation;
- More than one investigator;
- Budgets that exceed the yearly limitations given in Table 2; and/or
- Data analysis only

A panel of scientific peers of the proposers will evaluate compliant proposals using the criteria given in Section 4.2 below. A NASA/ISAS technical team will provide the peer panel with a technical evaluation of each proposal that will include an assessment of the ability of the mission to provide the required data. NASA may also seek to supplement the knowledge and expertise of the peer panel by obtaining mail-in reviews. The peer panel will have the right to accept, modify, or reject these mail-in reviews.

Once the panel evaluations are complete, an *Ad Hoc* Subcommittee of the Space Science Steering Committee (see below), composed wholly of Civil Servants, will convene to consider the evaluation results. This subcommittee will categorize the proposals in accordance with procedures required by NASA FAR Supplement Part 1872.0 according to the Categories defined below. Note that NASA anticipates selecting and funding only Category I investigations.

Category I. Well conceived and scientifically and technically sound investigation pertinent to the goals of the program and the AO's objectives and offered by a competent investigator from an institution capable of supplying the necessary support to ensure that the investigation can be delivered on time and within budget. Investigations in Category I are recommended for acceptance and normally will be displaced only by other Category I investigations.

Category II. Well conceived and scientifically or technically sound investigations that are recommended for acceptance, but at a lower priority than Category I.

Category III. Scientifically or technically sound investigations that require further development (does not apply to this Announcement).

Category IV. Proposed investigations that are recommended for rejection for the particular opportunity under consideration, whatever the reason.

The Space Science Steering Committee, which is composed wholly of NASA Civil Servants and appointed by the Associate Administrator for Space Science, will consider the results of the evaluations and categorizations. The Steering Committee will conduct an independent assessment of the evaluation and categorization processes regarding both their compliance to established policies and practices, as well as their completeness, self-consistency, and adequacy of all materials related thereto. After this review, the NASA MUSES-C Program Scientist will take the final evaluations and categorizations to the Source Selection Official who will make the final selections based on all of the factors outlined in section 4.2 below. For this AO, the Associate Administrator for Space Science has delegated the role of selection official to the Science Program Director for Solar System Exploration, Office of Space Science.

4.2 Criteria for Evaluation and Selection

NASA will use the evaluation criteria listed below to evaluate compliant proposals following the process described in Section 4.1. The evaluation factors (which are defined more fully in subsections below) are listed in descending order of priority.

- Scientific Merit;
- Technical Merit and Feasibility;
- Skills of Investigators; and
- Cost and Feasibility of Implementation Plan.

4.2.1. Scientific Merit

The goals and objectives of the proposed investigation will be assessed to determine the breadth, as well as depth, of the impact of the investigation on the understanding of asteroids in general and Nereus in particular. Another major element in this evaluation will be whether the data requirements as stated in the proposal will be sufficient to complete the proposed investigation.

4.2.2. Technical Merit and Feasibility

Each proposed investigation will be evaluated for its technical merit, feasibility, and the probability of success. Technical merit and feasibility will be evaluated by assessing the degree to which the MUSES-C mission, as described in this AO, can reasonably be expected to provide the data needed for the proposed investigation, as well as the degree to which the mission will support the acquisition of the required data. Other major elements include the proposed data analysis and archiving plan. Finally, the probability of success will be evaluated by assessing the experience and expertise of the Principal Investigator.

4.2.3. Skills Offered

For the U.S. investigators proposing for Orbiter imaging and Orbiter infrared science, the MUSES-C collaboration desires the following specific skills to help ensure mission success:

> Asteroid Multiband Imaging Camera: In order to assist in the calibration, the MUSES-C collaboration seeks expertise to help provide ground-based photometric observations of standard stars in the Eight Color Asteroid Survey system; and

Orbiter Near-Infrared Spectrometer: In order to provide a link between the spectral characterization of the target asteroid and a particular meteorite type, the MUSES-C collaboration seeks expertise in the area of meteorite spectra and near-infrared asteroid spectroscopy.

4.2.4. Cost and Feasibility of Implementation Plan

Each proposed investigation will be evaluated to assess the likelihood that it can be implemented, including both an assessment of whether the Principal Investigator will dedicate enough time to be effective during development, flight, and data analysis, as well as an assessment of the likelihood of completing the investigation within the proposed cost. In addition, an assessment will be made of the degree of support (logistics, facilities, etc.) that the proposing institution offers to provide in order to ensure that the investigation can be completed satisfactorily.

5. Implementation

Following selection, NASA will notify the PI's of the selected investigations immediately by telephone, followed by formal written notification. The formal notification will include any issues noted during the evaluation that may require resolution. NASA will notify all other proposers in writing that their investigations were not selected and will offer a debriefing. Such debriefings may be by telephone or, if the Principal Investigator prefers, may be conducted in person at NASA Headquarters. NASA funds may not be used to defray travel costs by the proposer for a debriefing.

6. Conclusion

The MUSES-C collaboration, with its Orbiter and Rover will enable important, new scientific research into the nature of the solar system's near-Earth asteroids. It will also enable 21st-century science missions through the development and validation of key new technologies. NASA's Office of Space Science invites and encourages your participation in this important activity.

Carl B. Pilcher
Science Program Director
for Solar System Exploration

Wesley T. Huntress, Jr.
Associate Administrator
for Space Science

Appendix A

General Instructions and Provisions

I. INSTRUMENTATION AND/OR GROUND EQUIPMENT

By submitting a proposal, the investigator and institution agree that NASA has the option to accept all or part of the offeror's plan to provide the instrumentation or ground support equipment required for the investigation, or NASA may furnish or obtain such instrumentation or equipment from any other source as determined by the selecting official. In addition, NASA reserves the right to require use of Government instrumentation or property that subsequently becomes available, with or without modification, that meets the investigative objectives.

II. TENTATIVE SELECTIONS, PHASED DEVELOPMENT, PARTIAL SELECTIONS, AND PARTICIPATION WITH OTHERS

By submitting a proposal, the investigator and the organization agree that NASA has the option to make a tentative selection pending a successful feasibility or definition effort. NASA has the option to contract in phases for a proposed investigation and to discontinue the investigative effort at the completion of any phase. NASA may desire to select only a portion of the proposed investigation and/or that the individual participates with other investigators in a joint investigation. In this case, the investigator will be given the opportunity to accept or decline such partial acceptance or participation with other investigators prior to a NASA selection. Where participation with other investigators as a team is agreed to, one of the team members will normally be designated as its leader or contact point. NASA reserves the right not to make an award or cancel this Announcement of Opportunity at any time.

III. SELECTION WITHOUT DISCUSSION

The Government intends to evaluate proposals and award contracts without discussions with offerors. Therefore, each initial offer should contain the offeror's best terms from a cost or price and technical standpoint. However, the Government reserves the right to conduct discussions, if later determined by the Contracting Officer to be necessary.

IV. NONDOMESTIC PROPOSALS

Since this program is based on a bilateral agreement between NASA and ISAS, this AO is open only to organizations in the U.S., as well as to nonaffiliated members of the resident U.S. scientific community.

V. TREATMENT OF PROPOSAL DATA

It is NASA policy to use information contained in proposals and quotations for evaluation purposes only. While this policy does not require that the proposal or quotation bear a restrictive notice, offerors or quoters should, in order to maximize protection of trade secrets or other information that is commercial or financial and confidential or privileged, place the following notice on the title page of the proposal or quotation and specify the information, subject to the notice by inserting appropriate identification, such as page numbers, in the notice. In any event, information (data) contained in proposals and quotations will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

RESTRICTION ON USE AND DISCLOSURE OF
PROPOSAL AND QUOTATION INFORMATION (DATA)

> The information (data) contained in (insert page numbers or other identification) of this proposal or quotation constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed for other than evaluation purposes; provided, however, that in the event a contract is awarded on the basis of this proposal or quotation, the Government shall have the right to use and disclose this information (data) to the extent provided in the contract. This restriction does not limit the Government's right to use or disclose this information (data), if obtained from another source without restriction.

VI. STATUS OF COST PROPOSALS

The investigator's institution agrees that the cost proposal submitted in response to the Announcement is for proposal evaluation and selection purposes, and that, following selection and during negotiations leading to a definitive contract, the institution may be required to resubmit or execute all certifications and representations required by law and regulation. Because the value of awards will be less than $500,000, submission of a Standard Form (SF) 1411 Contract Pricing Proposal Cover Sheet is not required.

VII. LATE PROPOSALS

The Government reserves the right to consider proposals or modifications thereof received after the date indicated for such purpose, if the selecting official deems it to offer NASA a significant technical advantage or cost reduction. (See NFS 18-15.412.)

VIII. SOURCE OF SPACE INVESTIGATIONS

Investigators are advised that candidate investigations for space missions can come from many sources. These sources include those selected through the Announcement of Opportunity, those generated by NASA in-house research and development, and those derived from contracts and other agreements between NASA and external entities.

IX. DISCLOSURE OF PROPOSALS OUTSIDE THE GOVERNMENT

NASA may find it necessary to obtain proposal evaluation assistance outside the Government. Where NASA determines it is necessary to disclose a proposal outside the Government for evaluation purposes, arrangements will be made with the evaluator for appropriate handling of the proposal information. Therefore, by submitting a proposal, the investigator and institution agree that NASA may have the proposal evaluated outside the Government. If the investigator or institution desires to preclude NASA from using an outside evaluation, the investigator or institution should so indicate on the cover. However, notice is given that if NASA is precluded from using outside evaluation, it may be unable to consider the proposal.

X. EQUAL OPPORTUNITY

For any NASA contract resulting from this solicitation, the clause at FAR 52.222-26, Equal Opportunity, shall apply.

XI. PATENT RIGHTS

A. For any NASA contract resulting from this solicitation awarded to other than a small business firm or nonprofit organization, the clause at NFS 18-52.227-70, New Technology, shall apply. Such contractors may, in advance of a contract, request waiver of rights as set forth in the provision at NFS 18-52.227-71, Requests for Waiver of Rights to Inventions.

B. For any NASA contract resulting from this solicitation awarded to a small business firm or nonprofit organization, the clause at FAR 52.227-11, Patent Rights--Retention by the Contractor (Short Form), (as modified by NFS 18-52.227-11) shall apply.

XII. RIGHTS IN DATA

Any contract resulting from this solicitation will contain the Rights in Data - General clause: FAR 52.227-14.

Appendix B

Guidelines for Proposal Preparation

The following guidelines apply to the preparation of proposals in response to an Announcement of Opportunity. The material is a guide for the proposer and not intended to be encompassing or directly applicable to the various types of proposals that can be submitted. The proposer should provide information relative to those items applicable or as required by the Announcement. In the event of an apparent conflict between the guidelines in this Appendix and those contained within the body of the AO, those within the AO shall take precedence.

I. General Guidelines

All documents must be typewritten in English, use metric units, and be clearly legible. Submission of proposal material by facsimile, electronic media, videotape, floppy disk, etc., is not acceptable. In evaluating proposals, NASA will only consider printed material. Proposals may not reference a World Wide Web site for any data or material needed to understand or evaluate the proposal.

The proposal must consist of only one volume, with readily identified sections corresponding to items A through F given in section III below. Note the guidance on page count for the various sections specified in Table B-1.

In order to allow for recycling of proposals after the review process, all proposals and copies must be submitted on plain white paper only (e.g., no cardboard stock or plastic covers, no colored paper, etc.). Photographs and color figures are permitted if printed on recyclable white paper only. The original signed copy (including cover page, certifications, and non-U.S. endorsements) should be bound in a manner that makes it easy to disassemble for reproduction. Except for the original, two-sided copies are preferred. Every side upon which printing appears will be counted against the page limits.

II. Page Limits

While there is no limit on the total size of the proposal, there are limits on the sizes of several key components. See Table B-1. Proposals may contain fold-out pages up to a size of 11 x 17 inches (28 x 43 cm), but such fold-out pages count as two pages on each printed side against the page limit. All pages other than fold out pages shall be 8.5 x 11 inches or A4 European standard.

Table B-1: Page Limits for Proposals

Section	Page Limits
A. Cover Page/Investigation Summary	Use form
B. Table of Contents	1
C. Description of Scientific Investigation	15
D. References	No limit
E. Resume, Relevant Experience, Curriculum Vitae	5
F. Management Plan and Budget	No limit

Single- or double-column format is acceptable. In complying with the page limit, no page should contain more than 55 lines of text and the type font should not be smaller than 12-point Times (i.e., approximately 15 characters per inch). Figure captions should be in 12 point. Figures and cost tables may contain smaller font as long as they are easily legible.

III. Contents of Proposals

The content of each proposal is described below.

A. COVER PAGE/INVESTIGATION SUMMARY

All proposals must be prefaced by an integrated Cover Page/Proposal Summary that contains important, required information (see below). Produce this item by first entering the requested information electronically through the World Wide Web site given in Section 3.1 of the AO. Section 3.1 also provides a point of contact for any proposer who does not have access to the Web or who experiences difficulty in using the specified site. Use a printed copy of the electronically submitted form to obtain original signatures of the PI and an official from the proposing institution to submit with the original copy of the proposal. In addition, use reproductions of this original *Cover Page/Proposal Summary* to preface the required printed copies of the proposal.

The electronic *Cover Page/Proposal Summary* form will provide a block of space (about one page in length) for a self-contained Proposal Summary of the proposed research activity. The Proposal Summary is intended to provide background and perspective to the interested reader and, therefore, should include the following key information:

- A description of the key, central objectives of the proposed research in terms sufficient for a nonspecialist not familiar with the document to grasp its essence;

- A statement of methods proposed to accomplish those proposed objectives; and

Note: NASA intends to publish the proposal title, the PI name and institution, and the Proposal Summary of every selected investigation in a public data base. Therefore, the Proposal Summary should not include proprietary information that would preclude its unrestricted release (see also Appendix A, Section V).

Changes (such as whiteout or strikethrough) to the printed Cover Page/Proposal Summary are not permitted. The proposer may make needed changes to the information submitted electronically only by editing the electronic submission following the instructions at the World Wide Web site given in Section 3.1 of the AO. After submitting the final Cover Page/Proposal Summary electronically, the proposer must then print the correct and final version and obtain the necessary signatures.

Note: The authorizing institutional signature now also certifies that the proposing institution has read and is in compliance with the three required certifications printed in full at the end of this Appendix. NASA does not, therefore, require institutions to separately submit these certifications with the proposal.

B. TABLE OF CONTENTS

The proposal should contain a table of contents which parallels the outline provided below in Sections C through F of this Appendix.

C. DESCRIPTION OF SCIENTIFIC INVESTIGATION

The description should include the scientific objectives of the proposed investigation, what data are needed in order to perform the investigation, operational constraints that must be met while acquiring the data, how the data will be analyzed, and how the data products will be used to achieve the scientific objectives.

Scientific Goals and Objectives. This section should consist of a discussion of the goals and objectives of the investigation, the value of the investigation to the scientific understanding of Nereus in particular, asteroids in general, and the overall advancement of the Solar System Exploration theme of Space Science, and the relationships to past, current, and future investigations and missions. It should describe the history and basis for the proposal and should discuss the need for such an investigation.

Data Requirements. The measurements to be taken in the course of the mission, the data to be returned, and the approach that will be taken in analyzing the data to achieve the scientific objectives of the investigation should be discussed. This description should identify the quality of the data to be returned (resolution, coverage, pointing accuracy, measurement precision, etc.), as well as the quantity of data needed (bits, images, etc.) for the proposed investigation. The relationship between the data products generated and the scientific objectives should be explicitly described, as should the expected results. The plan for producing and delivering data to the MUSES-C project computer in Japan and to the Planetary Data System should be described.

Mission Requirements. This section should describe expected requirements and constraints on the operation of the mission as the data are acquired.

Education/Public Outreach Requirements. In this section, the investigator must state that he or she will support education and public outreach activities within the MUSES-C collaboration.

D. References

This section may provide a list of reference documents used in the proposal. The documents themselves cannot be submitted, except as a part of the proposal and included within the prescribed page count.

E. Resume, Relevant Experience, Curriculum Vitae

This section should describe the capabilities of the Principal Investigator for carrying out the proposed investigation. A summary of relevant experience should be included, along with a short version of investigator's curriculum vitae. Proposers offering investigations using either the Orbiter Asteroid Multiband Imaging Camera or the Orbiter Near-Infrared Spectrometer should be sure to describe the skills and relevant experience being offered in support of the special needs for these instruments given in section 4.2.3.

F. Management Plan and Budget

The management plan should include a master schedule and a level of effort that the Principal Investigator commits to the project for each phase of the MUSES-C collaboration between ISAS and NASA.

The cost plan should summarize the total investigation cost using the categories of cost given below. The first page should give a summary for the total effort, covering all years, and the following pages should give a summary for each fiscal year beginning with Fiscal Year 1999.

The categories of cost should include the following:

1. **Direct Labor**--List by labor category, with labor hours and rates for each. Provide actual salaries of all personnel and the percentage of time each individual will devote to the effort.

2. **Overhead**--Include indirect costs. Usually this is in the form of a percentage of the direct labor costs.

3. **Materials**--This should give the total cost of the bill of materials, including estimated cost of each major item. Include lead time of critical items,

4. **Subcontracts**--List those over $25,000, specify the vendor and the basis for estimated costs. Include any baseline or supporting studies.

5. **Special Equipment**--Include a list of special equipment with lead and/or development time.

6. **Travel**--List estimated number of trips, destinations, duration, purpose, number of travelers, and anticipated dates.

7. **Other Costs**--Costs not covered elsewhere.

8. **General and Administrative Expense**--This includes the expenses of the institution's general and executive offices and other miscellaneous expenses related to the overall business.

9. **Fee** (if applicable).

If the effort is sufficiently known and defined, a funding obligation plan should provide the proposed funding requirements of the investigations by quarter and/or annum keyed to the work schedule.

IV. Certifications

The following pages contain, for reference only, copies of the three currently required Certifications. Note that the signature of the Authorizing Institutional Representative on the printed copy of the Cover Page submitted with the proposal now verifies that the proposing organization complies with these Certifications; therefore, these Certifications do not have to be independently signed and submitted as in previous Announcements of Opportunity.

Certification Regarding Debarment, Suspension, and Other Responsibility Matters

This certification is required by the regulations implementing Executive Order 12549, Debarment and Suspension, 34 CFR Part 85, Section 85.510, Participant's responsibilities. The regulations were published as Part VII of the May 26, 1988 Federal Register (pages 19160-19211).

(1) The prospective primary participant certifies to the best of its knowledge and belief, that it and its principals:

  (a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

  (b) Have not within a three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or contract under a public transaction; violation of Federal or State antitrust statues or commission of embezzlement theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

  (c) Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State or local) with commission of any of the offenses enumerated in paragraph (1)(b) of this certification; and

  (d) Have not within three-year period preceding this application/proposal had one or more public transactions (Federal, State, or local) terminated for cause or default.

(2) Where the prospective primary participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

Certification Regarding Lobbying

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000, and not more than $100,000 for each such failure.

Certification of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs

The *(Institution, corporation, firm, or other organization on whose behalf this assurance is signed, hereinafter called "Applicant ")* hereby agrees that it will comply with Title VI of the Civil Rights Act of 1964 (P.L. 88-352), Title IX of the Education Amendments of 1962 (20 U.S.C. 1680 et seq.), Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. 794), and the Age Discrimination Act of 1975 (42 U.S.C. 16101 et seq.), and all requirements imposed by or pursuant to the Regulation of the National Aeronautics and Space Administration (14 CFR Part 1250) (hereinafter called "NASA") issued pursuant to these laws, to the end that in accordance with these laws and regulations, no person in the United States shall, on the basis of race, color, national origin, sex, handicapped condition, or age be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity for which the Applicant receives federal financial assistance from NASA; and hereby give assurance that it will immediately take any measure necessary to effectuate this agreement.

If any real property or structure thereon is provided or improved with the aid of federal financial assistance extended to the Applicant by NASA, this assurance shall obligate the Applicant, or in the case of any transfer of such property, any transferee, for the period during which the real property or structure is used for a purpose for which the federal financial assistance is extended or for another purpose involving the provision of similar services or benefits. If any personal property is so provided, this assurance shall obligate the Applicant for the period during which the federal financial assistance is extended to it by NASA.

This assurance is given in consideration of and for the purpose of obtaining any and all federal grants, loans, contracts, property, discounts, or other federal financial assistance extended after the date hereof to the Applicant by NASA, including installment payments after such date on account of applications for federal financial assistance which were approved before such date. The Applicant recognized and agrees that such federal financial assistance will be extended in reliance on the representations and agreements made in this assurance, and that the United States shall have the right to seek judicial enforcement of this assurance. This assurance is binding on the Applicant, its successors, transferees, and assignees, and the person or persons whose signatures appear below are authorized to sign on behalf of the Applicant.

NASA Form 1206

Appendix_C:
MUSES-C_Mission_Description

Disclaimer

This Proposal Information Package has been prepared in good faith with the best available information. This mission, however, is still early in the design phase.

While every effort will be made to implement the designs described herein, budgetary/ programmatic/ technical problems may occur during development which may result in changes to the missions or instrument specifications in order to meet cost constraints or other driving requirements.

MISSION DESCRIPTION

TABLE OF CONTENTS

List of Tables

List of Figures That Can Be Found at Internet URL <http://muses.larc.nasa.gov/muses>

Table 1. MUSES-C Schedule of Events

(Although dates are given for a candidate alternative mission, proposers are reminded that proposals will be evaluated only with respect to the baseline mission to 4660 Nereus)

Mission Event	Baseline Mission to 4660 Nereus	Candidate Mission to 1989 ML
MUSES-C Rover PDR; MUSES-C PM Review	February/March 1998	
MUSES-C Rover CDR	October 1998	
MUSES-C Rover Engineering Model instruments and filter fabrication complete	April 1, 1999	
MUSES-C Rover Flight Model instruments and filter fabrication complete	January 1, 2000	
Instrument calibration complete	July 1, 2000	
Rover delivered to ISAS	September 1, 2000	
MUSES-C spacecraft and instrument integration and test	2001	
Launch	January 7, 2002	July 5, 2002
Asteroid arrival	April 6, 2003	October 20, 2003
Mapping phase	April 6 - 26, 2003	October 20 - November 9, 2003
Sampling activities and Rover mission	April 26 - May 23, 2003	November 9, 2003 - April 8, 2004
Asteroid departure	May 30, 2003	April 15, 2004
Asteroid samples returned to Earth; U. S. investigator studies samples in Japan	January 20, 2006	June 5, 2006
Portions of asteroid samples given to U. S.	January 28, 2007	June 5, 2007

Table 2. MUSES-C At a Glance

Mission Goals: The primary mission goals are to demonstrate four key technologies requisite for future advanced Sample Return missions. These technologies include spacecraft autonomous rendezvous and sampling with optical aid, solar electric propulsion, the sample collection and sealing techniques, and the hyperbolic reentry of the sample capsule at Earth. MUSES-C is a technology demonstration mission that will rendezvous with a near-Earth asteroid and deliver science instruments to the close proximity of an asteroid's surface and to the surface itself. Remote sensing and surface science measurements will be made. Important science goals include the characterization of the asteroid's physical structure and chemical composition. A major technology and science goal is to collect and return asteroid surface samples to Earth for detailed laboratory analysis.

The major goals for the MUSES-C Rover are to demonstrate its low-gravity mobility and to take high resolution images and spectra of the asteroid's surface.

Spacecraft: Single 3-axis stabilized spacecraft, plus Earth reentry capsule. Body-fixed instruments. Solar-powered. Solar-electric propulsion. TBD [485] kg.

Spacecraft Payload Characteristics:
Mass (not including sample collection mechanism): 6 kg
Power: ~60 W
Communications: X-band up and X-band down
Data Storage Capability: 256 Mb (8 Mb/day for Rover data)
Downlink data rates: 8 kbps (Nereus), 4 kbps (1989 ML)

Launch Vehicle: M-V. Launch from Kagoshima, Japan.

Spacecraft Instruments Open for Proposals:
Imaging Camera (AMICA)
LIDAR
IR Spectrometer (NIRS)

Instruments Not Open for Proposals:
X-Ray Spectrometer (XRS)

Rover: Single solar-powered Rover with ability to point instruments in any direction.

Rover Characteristics:
Mass: 1250 grams
Power: 2.9 W
Communications: 38.4 kbps link to Orbiter (can be as low as 2.4 kbps)
Data Storage Capability: Data transmitted to Orbiter

Rover Instruments Open for Proposals:
Alpha X-Ray Spectrometer (AXS)
Imaging Camera
Near-IR Spectrometer

1. MISSION DESCRIPTION

1.1 MUSES-C Baseline Mission Description

The MUSES-C mission will be launched on a single Japanese M-V launch vehicle from Kagoshima, Japan in January 2002. The heliocentric orbit flown by MUSES-C from launch to rendezvous with 4660 Nereus can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Following launch and injection into the heliocentric transfer orbit, the spacecraft will switch on its low-thrust Solar Electric Propulsion (SEP) system. No scientific observations are planned by the Orbiter during cruise (with the exception of in-flight calibrations). The Rover and it's instruments are not operated during cruise. The spacecraft will arrive at 4660 Nereus in April 2003

As this AO is released, data on Nereus (and the candidate alternative target, 1989 ML) is sketchy at best. Nereus appears to be a small asteroid; key parameters of Nereus and 1989 ML are listed in Table 3 . Observations of the target asteroid just before launch may provide better estimates in some areas.

Table 3. Nominal Asteroid Parameters

Property	Baseline Nereus	Candidate 1989 ML
Absolute Magnitude	18.5	19.5
Albedo Limits	0.04 - 0.15	0.04 - 0.15
Effective Radius (km)	0.3 - 0.7	0.2 - 0.4
Bulk Density (g/ cc)	1 – 4	1 – 4
Rotation Period (hrs)	15.2	> 4
Spectral Class	C, F, or EMP	C (uncertain)
Escape Velocity (m/sec)	0.22 - 1.05	0.15 - 0.60
Surface Gravity (cm/sec^2)	(0.8 - 8.0)x10^{-2}	(0.6 - 5.0)x10^{-2}
Perihelion (AU)	0.95	1.10
Aphelion (AU)	2.03	1.45
Orbital Period (yrs)	1.82	1.44

The MUSES-C spacecraft will arrive at Nereus on April 6, 2003, at a distance of 1.85 AU from the Sun. Although the spacecraft is often called the Orbiter, it will not go into orbit about Nereus; rather, it will hover at a distance of 20 km. The spacecraft is solar-powered, and the solar panels, along with the antenna and science instruments, are body-fixed. The spacecraft will, therefore, be oriented such that the spacecraft will receive maximum power through the solar panels while the instruments, mounted on the bottom of the spacecraft, are pointed at the asteroid. The operations period at the asteroid is partitioned as shown in Table 4. Since the Rover transmits data to the spacecraft for relay to Earth, there will be no planned communications with the Rover after the Orbiter departs, signaling the end of the Rover operations.

Table 4. Mission Operations at Nereus (2003)

MUSES-C Mission Phase	**Nominal Dates 2003**	**Duration (days)**	**Approx. Range from Sun (AU)**	**Approx. Range from Nereus (Km)**
Asteroid Arrival	April 6		1.8	
Mapping Phase	April 6 - 26	20	1.7	20 - 50
Sampling and Rover Activities	April 26 - May 23	27	1.7	0 - 20
Leave Asteroid	May 30		1.6	

Preliminary sample collection sites will be selected during the mapping phase. Once the mapping phase is complete, the spacecraft will descend toward Nereus in stages, as the asteroid shape and gravity models are refined. Rendezvous and descent is autonomous, using cameras and a LIDAR to get to an altitude of 50 m. Once a primary sample site is chosen, the spacecraft will descend to touch down on the asteroid. At an altitude of about 500 m (TBD), the Orbiter will drop a target marker onto the surface. The target marker will be used for navigating the spacecraft to the correct sampling site using a laser range finder and a fan beam sensor. At a height of about 20 m, the Orbiter will hover and drop the Rover onto the asteroid. The Orbiter will then free-fall to the surface without using thrusters. At Orbiter touchdown, a pellet will be shot into the asteroid at 300 m/sec, and a horn on the spacecraft will funnel the impact ejecta into the sample collection device as the spacecraft begins to ascend to its nominal altitude of 20 km. An illustration of the Orbiter at touchdown can be found at Internet URL <http://muses.larc.nasa.gov/muses>. Up to three samples will be collected from different sites on the asteroid. The expected sample mass collected is roughly 5 to 10 grams. The samples will be collected in different containers and then stored in hard-vacuum in the sample return capsule.

The total stay-time at Nereus is 8 weeks. Communications during Nereus operations occurs once daily through the 64 m dish at Usuda (Japan) with an augmentation of 10 passes over the 8-week period through NASA's Deep Space Network. The data rate to Earth from the spacecraft is 8 kbps at the asteroid. The spacecraft will be oriented such that its solar panels are pointed to the Sun continuously. All instruments are mounted on the bottom face of the spacecraft and are nadir-pointed. The high-gain antenna is oriented so it can be Earth-pointed. An illustration of the MUSES-C spacecraft with the solar panels and sampler horn in the stowed condition can be found on the Internet at URL <http://muses.larc.nasa.gov/muses>.

The spacecraft leaves Nereus for Earth on May 30, 2003. No Orbiter cruise science is planned. Arrival at Earth is on January 20, 2006, and sometime around 4-12 hours prior to reentry, the sample capsule will separate from the spacecraft. The spacecraft will perform a deflection maneuver to avoid reentering with the capsule. The capsule will enter the atmosphere at about 12 - 13 km/sec using an ablative heat shield. The heat shield will be jettisoned and a parachute will allow the capsule to land with an impact velocity of around 6-10 m/sec. The planned landing site is the Utah Test and Training Range operated by the USAF. Once recovered, the capsule will be returned to ISAS personnel. At this time, it is unclear as to what type of intermediate containment or quarantine of the sample might be necessary. During the first year after sample recovery, a NASA Sample Team Member will spend time in Japan and examine the samples alongside the ISAS MUSES-C science team members. After an agreed-upon time interval [one year], a portion of the sample will be given to NASA for distribution among scientists selected through a NASA Research Announcement. It is presently planned that ISAS will transfer to NASA 10 % of the total sample mass.

1.2 MUSES-C Rover Baseline Mission Description

The MUSES-C Rover mission begins when the Rover is ejected from the MUSES-C spacecraft onto Nereus. Prior to release, the solar-powered Rover sits inside the Orbiter-Mounted Rover Equipment (OMRE). While attached to the spacecraft, the Rover is shielded from the Sun. The OMRE is the Rover's interface to the spacecraft and contains an antenna/receiver for Rover-OMRE communication and a data line for data transfer. The Rover will uplink at least 8 Mb of data a day at up to 38.4 kbps to the spacecraft; these data will include both science and engineering data and will be compressed appropriately in consultation with the engineering and science teams. The MUSES-C spacecraft will downlink at least 8 Mb of Rover data a day to Earth by agreement between ISAS and NASA.

Once the Rover is dropped from the spacecraft, it is expected to bounce a few times before coming to rest on the surface of the asteroid and will then orient itself. The maximum speed the Rover can travel is about 1.5 mm/sec without losing surface contact. Due to the low-gravity environment, the Rover has been designed with the capability to right itself if it flips onto its back. Since the four posable struts are independent, the Rover can be commanded to point itself in any orientation. A pointable mirror and actuated focus mechanism allow the Rover to take panoramic images as well as microscopic ones.

The primary Rover objectives are to carry out scientific measurements with its entire instrument suite and to transmit the data before asteroid "night," at which time the Rover will shut down until sunrise. There is little nonvolatile storage on the Rover (at most 64 Kbytes), so most data not transmitted to the Orbiter at the end of the daily investigations schedule will be lost. Daily investigations include visual imaging of the terrain and targets of interest, point spectra in the infrared, AXS spectra, and soil mechanics investigations using the Rover as an instrument.

Understanding the orientation of the rotation axis of the asteroid with respect to the Sun will be critical for Rover placement on the surface to ensure maximum operational periods. As a technology experiment, the Rover is being designed with the capability to “hop” in low-gravity. If the experiment is successful, the Rover may be able to transverse long distances [10 - 100 m]. This behavior may enable the Rover to stay in the Sun longer to take more data and avoid thermal cycling. The Rover may try to reach and look inside one or more of the craters left by a sampling event to ascertain stratigraphy which will be lost in the collected sample; it will also seek evidence for sample modifications due to the impact process. The nominal Rover mission ends when the Orbiter departs Nereus. As a technology experiment, the Rover may include an experimental optical communications capability. This capability, if implemented, may enable low-rate communications between the Rover and Earth after the departure of the MUSES-C spacecraft until the demise of the Rover.

1.3 Facility Instruments on the MUSES-C Orbiter

The Facility Instrument complement on the MUSES-C Orbiter (see Table 5) is expected to consist of the following instruments: Asteroid Multi-Band Imaging Camera (AMICA), LIDAR, Near IR spectrometer, X-Ray Spectrometer, and the sample collection mechanism. **The X-Ray spectrometer is not open for proposals.**

Table 5. MUSES-C Orbiter Instrument Capability Summary (Preliminary)

Instrument	**Capability**
Asteroid Multi-band Imaging Camera (AMICA)	5-6° square field of view 1000 x 1000 pixel CCD 8-position filter wheel
Near Infrared Spectrometer (NIRS)	0.85 - 2.1 μm spectral range Spectral resolution 0.025 μm
Light Detection and Ranging Instrument (LIDAR)	Operates within 50 km of surface with ±10 m range accuracy at 50 km Beam divergence: ~0.5 mrad
X-Ray Spectrometer (XRS)	1024 x 1024 pixels, 1” CCD x 4 chips, 5°x5° FOV, energy range: 1 – 10 keV
Sample Collection Mechanism	Up to 3 separate samples

1.3.1 Science Objectives and Experimental Approach

Scientific objectives for the imaging camera (AMICA) are:

Characterize the surface morphology and the processes that affect the asteroid's surface

Determine the global size, shape, and volume of asteroid.

Determine the asteroid's spin state.

Establish a global map of surface features and colors.

Reveal history of impacts from other asteroid and comet fragments.

Search for possible asteroid satellites and dust rings.

Determine optical parameters of the surface using polarization degree vs. phase curve at large phase angles.

Science objectives for the LIDAR are:

Provide accurate shape and mass determinations for asteroid.

Map asteroid's surface with a maximum resolution of about 10 meters.

Map global surface albedo at a wavelength of 1 micrometer.

Science objectives for the Near IR Spectrometer (NIRS) are:

Map mineralogic composition of asteroid and provide main evidence for rock types present on surface at scales as small as 20 m

Characterize surface heterogeneity

Together with elemental composition measurements provided by the XRS and color imagery from the camera, NIRS will provide a link between asteroids and meteorites.

Science objectives for the Sample Collection Mechanism are:

Obtain up to three samples of asteroid material

Store samples is a hermetically sealed container for return to Earth

Science Objectives for the X-Ray Spectrometer are:

Map the major elemental composition of the surface as the asteroid rotates under the spacecraft.

Determine the major elemental composition at localized areas during asteroid approach phases.

Measure surface composition accurately enough to establish relationship between asteroids and meteorites and identify type of meteorite to which asteroid is linked.

Provide elemental abundance maps to investigate inhomogeneity of regolith.

1.3.2 Descriptions of MUSES-C Facility Instruments Available for Proposals

Descriptions of each of the MUSES-C Facility Instruments available for this proposal are given in this section. A figure depicting the constraints on fields of view of the instruments can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Asteroid Multi-band Imaging Camera (AMICA)

The Asteroid Multi-band Imaging Camera (AMICA) denotes the ONC-T (Optical Navigation Camera – Telescope) when this instrument is operated in the science mode with the filter wheel. An illustration of the camera can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Camera Specifications

AMICA consists of relatively simple refractive optics, a low dark-current CCD of frame transfer type, an eight-position filter wheel, and four-position glass-plate polarizers. Table 6 lists the main characteristics of the camera.

AMICA Management

Science Team Leader: Tsuko Nakamura (National Astronomical Observatory, Mitaka)
Science Team Member: Akiko Nakamura (Kobe University), Sho Sasaki (Tokyo Univ.),Jun Saito (Nishimatsu Construction Co. Ltd.)

Table 6. AMICA Specifications (preliminary)

Parameter	Specification
Mass (camera, electronics)	590 grams (including filter wheel and hood), 3.15 kg TBD
Power (camera, electronics)	6.8, 9.5 Watts
Dimensions	40 x 40 x 130 mm
Lens diameter	25 - 30 mm
Optics	F/5 refractor telescope (f=120-130 mm, fixed focus)
Field of view	5-6 square degrees (or roughly 0.1 square radian)
CCD	Frame transfer type with electronic shuttering 1000 x 1000 pixels
Pixel resolution	20 arcsec/pix (1m/pix at 10 km height)
CCD temperature	~ -20 deg C near Nereus
Stellar limiting magnitude	4-5 mag (V)
Quantum efficiency	approximately 80% at 500 nm
A/D conversion	12 bits
Spectral transmission of the system	430nm-1055nm
CCD saturation	60,000-100,000 electrons/pixel
Frame memory storage	3 full-frames (3 Mbytes)
Data recorder	30-40 Mbytes (tentative)
Filter-bands	Filters nearly equivalent to the ECAS (Eight Color Asteroid Survey) system and a wide-band filter (V-band) are planned for implementation. 1. b: 430 nm (110 nm), 2. bl: 480 nm (70 nm), 3. vw: 545 nm 100 nm), 4. w: 705 nm (68 nm), 5. x: 860 nm (80 nm), 6. p: 955 nm (83 nm), 7. z: 1055 nm (90 nm), 8. close-up lens. Figures in parenthesis are FWHM values.
Filter diameter	20 mm
Polarizer	Glass polarizer (~3x3 mm), 4 position angles (attached to CCD cover glass). Note that this polarimeter is used not as an imager but as a photometer.

Light Detection and Ranging Instrument (LIDAR)

The LIght Detection And Ranging instrument (LIDAR) is an altimeter to be launched with the MUSES-C spacecraft. It will be built by TOSHIBA of Japan. The LIDAR has the function of measuring the distance between the spacecraft and the surface of the target asteroid (4660 Nereus).

The size of the LIDAR is approximately 200 mm x 220 mm x 240 mm. It weights about 2.6 kg and consumes about 24 W of power while measuring distances. A complete list of specifications is presented below.

The LIDAR consists of the transmitter and the receiver. The transmitter uses a diode-pumped neodymium-yttrium-aluminum-garnet (Nd-YAG) laser, and the receiver uses a compact reflecting telescope with a diameter of 110 mm, made of porous SiC material, and enhanced hybrid silicon avalanche photodiode detector.

LIDAR Specifications

LIDAR specifications are listed in Table 7. A diagram of the LIDAR can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Table 7. LIDAR Specifications (Preliminary)

Parameter	**Specification**
Mass	2.6 kg
Power	24.3 W
Volume	200 mm (deep) x 220 mm (high) x 240 mm (wide)
Laser wavelength	1.064 μm
Range accuracy requirement	±10m at 50 km ±1m at 50 m
Range requirement	50 m - 50 km
Pulse repetition rate	1 pps
Pulse energy	10 mJ
Pulse divergence	0.5 mrad
Receiver aperture	110 mm

Laser Altimeter

The LIDAR directly measures the range between the spacecraft and the asteroid. The transmitter generates a brief laser pulse, and the instrument measures the time required for the light to reach the asteroid and return. When the asteroid is 50 km away, the LIDAR initiates the range measurements used for navigation of the spacecraft while approaching the asteroid. The LIDAR continues its measurement of the distance from 50 km to 50 m from the asteroid. The Laser Rangefinders (LRF) will operate, in place of the LIDAR, below 100 m from the surface. A curve of LIDAR signal vs. range can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

This ranging function of LIDAR will be used to measure the gravitational field of the asteroid. The time scale required for free fall of the spacecraft from point A to point B will be measured, and together with the distance between A and B measured by the LIDAR, an estimate of the asteroid's mass can be determined. This information may address fundamental questions concerning the internal structure of the asteroid. Theoretical simulations for the free fall trajectories of the spacecraft suggest that under the condition of the initial radial velocity <25 cm/s , the initial transverse velocity of < 1 cm/s, and the angle between the line of sight of the LIDAR and the line of the spacecraft to the center of the mass of the asteroid < 1 deg., we can estimate the mass of the asteroid with an error less than ±1%.

Although the LIDAR has no gimbal mechanism, the slow variation of its line-of-sight caused by the oscillation of the spacecraft yields the possibility of mapping part of the asteroid's surface. The diameter of the LIDAR beam spot on the surface of the asteroid is about 10-20 m at a distance of 20 km from the surface. The angular velocity of the LIDAR beam is 0.03 deg/s. The resulting map will provide information on the shape of the asteroid and its surface topography.

LIDAR Management

Science Team Leader : Tadashi Mukai (Kobe Univ.)
Science Team sub-Leader : Hiroshi Araki (NAO Mizusawa)
Instrument Scientists : Takahide Mizuno (ISAS)

Near IR Spectrometer (NIRS)

Near IR Spectrometer Specifications

NIRS Specifications are shown in Table 8. An illustration of the Near IR Spectrometer can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Table 8. NIRS Specifications (Preliminary)

Parameter	Specification
Total mass	2.6 kg [TBD]
Total power	21.5 W [TBD]
Focal Plane Linear Array	InGaAs (PV), 64 channels
Wavelength resolution	0.85 - 2.1 μm 0.025 μm
Array size	3.2 mm x 0.1 mm
Pixel size	30 μm x 100 μm
Field of view	0.1 x 0.1 deg
Spatial resolution (20 km distance)	34 m x 34 m
Total F number	1.06
Effective lens diameter	27 mm
Pixel pitch	50 μm
Operating temperature	263 K (Peltier cooled)
A/D resolution	12 bits

NIRS Management

Principal Investigator: Masanao Abe (ISAS)

Sample Collection Mechanism/Sample

The sample collection mechanism is designed to collect asteroid samples from three different locations on the asteroid. In order to collect a sample, the feed horn on the -Z side of the spacecraft must touch down on the asteroid. At touchdown, a projectile is shot into the asteroid through an opening in the feed horn. The impact velocity is about 300 m/sec. The ejecta from the projectile's impact is funneled through the feed horn and into the sample catcher which then rotates to expose the next open collection area. A few seconds after touchdown, the spacecraft lifts off the asteroid to a nominal altitude of 20 km. The spacecraft then hovers until it's time to collect the next sample. Sample sites will be selected by the sample scientists with the approval of the mission manager (for mission safety assessments). Site selection will be based on in-situ data gathered during the mapping phase of the mission. An illustration of the Sample Collection Mechanism and an illustration of the sample catcher can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Once all samples have been collected, the sample catcher is inserted into the sample container inside the sample return capsule. A latch mechanism releases and allows a spring to push the sample catcher into the sample container. The samples are then vacuum sealed inside the sample return capsule.

After return to the Earth, the samples will be returned to ISAS. The sample Team Member selected from the U. S. side will go to Japan and work side by side with the Japanese scientists to analyze the samples. After one year, the U. S. will receive a portion of the asteroid samples to be studied in U. S. laboratories. Scientists will be selected to work on that portion of the sample via a separate NRA. A Japanese scientist will be invited to the U. S. to work side by side with U. S. researchers to analyze the samples.

Sample Collection Management

Principal Investigator: Akira Fujiwara (ISAS)
Team Members:
Kazuo Tsuchiya (Osaka Univ.), Kazuyoshi Takayama (Tohoku Univ.),
Kouki Fukuda (Tohoku Univ.), Kazuya Yoshida (Tohoku Univ.),
Masanao Abe (ISAS), Jun'ichiro Kawaguchi (ISAS), Shujiro Sawai (ISAS),
Takeshi Higuchi (ISAS), Toshiya Hanada (Kyushu University), Sunao Hasegawa (ISAS).

1.4 Facility Instruments on MUSES-C Rover

The Facility Instrument complement on the MUSES-C Rover (see Table 9) is expected to consist of three primary instruments: Panoramic and Near-Imaging Camera (PANIC), Near-Infrared Spectrometer (NIS), and Alpha X-Ray Spectrometer (AXS).

Table 9. MUSES-C Rover Instrument Capabilities

Instrument	Capability
Panoramic and Near-Imaging Camera	512x512 (minimum 256 x 256)Active Pixel Sensor, 11.9 micron pixels (max 20 micron) Two(or three)-position focus camera with a scannable mirror to find spots in focus 10-position filter wheel (6 for science)
Near-Infrared Spectrometer	0.9 - 1.7 μm spectral range Spectral resolution <20 (expect 5)nm
Alpha X-Ray Spectrometer	Measures elemental abundances of surface soils and rocks

1.4.1 Measurement Objectives and Experimental Approach

The MUSES-C Rover instrument complement will allow characterization of the local texture, elemental composition, mineralogy, and morphology of the asteroid surface layers at scales smaller than 5 cm. The instrument suite will also allow investigations of lateral heterogeneity and vertical regolith structure. Further, the instrument complement will constrain the mechanical and thermal properties of the surface layer. Through complementary measurements at larger scales by the MUSES-C spacecraft, the science teams will be able to relate surface mineralogy and morphology, constrain surface composition, and enable comparisons with major meteorite types.

The Rover can only carry out these objectives while it is on the surface of the asteroid. Once the Rover is on the surface, it will be commanded daily to carry out its objectives via scripts written to live within the predetermined power modes. Due to the small size and mass of the Rover, only 2.9 W (maximum) are available to the Rover at any given time, so activities must be cycled.

1.4.2 Descriptions of MUSES-C Rover and Facility Instruments

Descriptions of each of the MUSES-C Rover and Facility Instruments are given in this section.

Rover Characteristics

The key Rover characteristics are listed in Table 10. Since the asteroid is small compared to the 20 km stand-off distance of the spacecraft, the Rover can communicate as long as it is powered and has a direct line-of-sight to the spacecraft.

Table 10. Rover Characteristics

Rover Characteristic	Value
Mass	1250 grams
Size	14 x 14 x 6 cm
Power	2.9 W (at 45 deg. incidence)
Max. velocity, rolling contact in microgravity	1.5 mm/ sec
Data rate	Up to 38.4 kbits/sec, as low as 2.4 kbits/sec

The Rover consists of a rectangular body which is 14x14x6 cm in dimension with four wheels on four posable struts for mobility. The wheels are 6.5 cm in diameter and 3 cm wide, and are mounted on struts which extend in pairs from hubs emerging from the geometric center of two opposing 14x6 cm faces of the body. Each strut is 7 cm long from the center of their pivot to the center of the wheel axis. Each of the six faces of the Rover body has solar cells affixed to it so that some power can be generated when the Rover is illuminated by the sun from any angle. The top face will deliver a power output, with 80% fill factor and oriented at 45 degrees to the sun vector at 1.12 AU from the sun, of 2.9 Watts. The top face also has the elements needed to radiate the radio signal from the RF communication subsystem, with no expectation that the RF signal strength will be significant outside the hemisphere above the top face. The Rover cannot conduct scientific investigations if the Sun is more than 1 radian off the normal vector to the Rover’s top surface. An illustration of the Rover can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

The main chassis of the Rover is rectangular. Each exterior face has the solar panel mounted on its corresponding substrate. The solar panels will stay near radiative equilibrium with the sky and thus range from 115 C at local noon to about -155 C just before sunrise. The thermal operating range of the instruments is -80 C to 30 C.

All instruments will fit inside the Rover body. There will be a view window on the front face for the NIS and PANIC. The AXS sensor will open out to the rear of the Rover and be placed in contact with rock or regolith by appropriate body/strut motion.

The mobility subsystem of the Rover (the four wheels, four struts) is designed to support nominal mobility and body-pose functions in full Earth gravity for testing and also designed to allow significant hops in the expected worst-case microgravity environment of 6 μg of surface acceleration and an escape velocity of about 15 -105 cm/sec. The Rover mobility system will maintain the mechanical configuration of the Rover if power is lost.

The surface gravity on Nereus is expected to be 8 to 80 μg and the escape velocity will be 0.2 to 1 m/s. With this low gravity, the gravitational force on an 850 gram Rover would be less than 0.08 grams of force. Depending on the model used for the surface properties of the asteroid, this low, normal force could imply certain mobility problems for conventional wheeled vehicles. If the surface is modeled as having conventional friction (e.g. coulombic friction), then the mobility characteristics of a vehicle in the asteroid environment will be a slow-motion version of the dynamics of an off-road vehicle on Earth. At 1 cm/sec, the dynamics would be similar to that of a dune buggy racing across the sand: the kinetic energy of the vehicle will be sufficient to lift the vehicle several vehicle lengths vertically in the gravity field. Except for the longer time constants, the motion of the vehicle will be directly scaled from the corresponding motions on Earth. For example, with a coefficient of friction (μ) =0.2 and an assumed gravity of 20 μgs, a vehicle acceleration of 4μg's can be achieved. Achieving a final velocity of 1 cm/sec from a standing start will take (using $V^2=2as$) a distance of s=1.3 meters, and (from V=at) a time of t=250 seconds. During this 4-minute period, the wheels will likely be slipping on the asteroid. If the vehicle hits a 0.5 cm bump on the surface of the asteroid, computer simulations show that it will go more than one vehicle length into the sky and frequently overturn. For this reason, as well as the desire to be ejected from the host spacecraft at an altitude of a few tens of meters, the Rover has been designed to be self righting and to be able to operate upside down. The concussion of hitting the surface at 1 cm/sec or after falling from 10s of meters of height is no more than falling a few millimeters on Earth.

Another plausible model for the surface properties of Nereus is that it may be somewhat "sticky". A reasonable model is that any part of the Rover which touches the asteroid surface will stick with a contact pressure of about 20 Pascals (nt/m^2) but perhaps as much as 1000 Pa (about 0.15 psi), as estimated for lunar and Mars drift material at the various landing sites. The contact area which is required to support the weight of the Rover is very small, even if the Rover has impacted from a great height. For example, if the Rover falls from an altitude of 50 meters, it will hit the surface with a velocity of 14 cm/sec and a kinetic energy of 4 mJ. If the Rover has wheels 6 cm in diameter and 3 cm wide, and two wheels take all the impact into material which crushes at the assumed compressive strength of 1 kPa, then the swept volume of the crushed soil at impact will be 4 cc. The crush depth for the two wheels turns out to be 3.3 mm and the surface area of the wheels which is then in contact with the soil is a total of 17 cm^2. At the extreme upper bound of 1 kPa the cohesive force on the Rover due to the soil is then 1.7 nt or 170 grams of force. This is about 5000 times as great as the "weight" of the vehicle. For the vehicle to move in this condition, it needs to break free from the soil cohesion to the wheels. This requires the use of the active articulation mechanism that allows self-righting and hopping, in this case to push away with the other wheels so that all the wheels have roughly equal cohesion. Then it will be important for the rear wheels to break away first (e.g. spin the rear wheels just before starting the front wheels) so that there is no cohesive action which will cause the vehicle to perform a "wheelie" and flip over on its back. Once the rear wheels are free of the soil cohesion, the front wheels can be started and the vehicle will move more or less as analyzed above. The accelerations may be much greater and the time scales shorter, however, due to the cohesion allowing the vehicle to get better traction. These algorithms will be developed and refined in a vacuum chamber with a precise counterbalance for the static weight of the Rover.

For longer-range mobility, hopping is planned. A brief description of a long-distance hop will help to identify some of the inherent technical challenges. An asteroid or comet rendezvous mission would generally call for an orbiting vehicle and a landed component such as a Rover. The Orbiter will map the gravity field of the asteroid. Using that gravitational model, a computer on the Orbiter or at Earth will compute a hop trajectory for the Rover to reach a desired science target. This will define the desired hopping take-off forces (direction and magnitude). The Rover will be commanded to actuate its wheels and struts in such a way as to provide the desired takeoff forces. As it leaves the surface, the uncertain surface composition and inhomogeneity will mean that the departure velocity will not be quite what was desired and so the trajectory will not be exactly what was planned. This means that the exact time of flight and the point of impact will not be known. At this point, the Rover may be slowly tumbling due to the unpredictable take-off forces and torques. The Rover must despin using its wheels and struts. This zero-g maneuver (in free fall) is similar to the motions that an upside-down cat uses to flip itself as it falls in order to land on its feet. Landing on its wheels is one of the primary goals of the Rover during the hop. This is important so as not to damage the solar cells or optical window of the Rover, and also to allow the wheels/struts to absorb impact forces to eliminate rebound as much as possible. As the Rover falls along the trajectory, the variations in the gravitational field (due to its irregular shape) will perturb the orbit from the planned orbit. This is an additional reason why it will be difficult to predict the time and place of impact based on dynamic models. An illustration of this hop maneuver can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

In the final phase of the fall, the Rover must orient its struts to land on the wheels and absorb the landing shock as much as possible. After the impacts, it is possible that the Rover will bounce off the surface for a smaller hop. This hop will have the same features as the main hop except that the time of flight will be much shorter.

The Rover will have proximity sensors for hazard avoidance, and can, of course, also sense when the lower solar panel current output drops sharply as the terrain under it becomes mostly shadowed by the Rover itself. Since the Rover has a prior estimate of the time of impact from image processing, it can pose itself so that the wheels and struts are down on the terrain side of the vehicle at the time of impact. When the proximity/solar panel output indicates that impact is imminent, then a recoil maneuver can be initiated which will limit the forces on the vehicle and the terrain. These forces can be very precisely controlled (this same feature also allows relatively precise hopping velocity control limited mainly by the uncertain mechanical properties of the surface).

During the hop and the landing events, the forces exerted on the surface by the wheels may be roughly equivalent to operation of the vehicle in 0.1 Earth gravity. Thus the forces that can be imparted may permit measurement of the soil mechanics properties. The primary sensor (since the Rover carries no accelerometer) for this would be to measure the motor current of the strut and wheel motors during the hop and the landing. The wheels are expected to have a 100:1 planetary gearhead, and the struts are expected to have an addition 3:1 bevel gear. These gearheads should be relatively easily backdrivable, and so the motor current will give at least some indication of the resistance to motion experienced by the motors.

For precise motion of the Rover to nearby target locations, the Rover will roll slowly. For a wheel radius of 3 cm and a surface acceleration of 20 μgs the corresponding velocity is 2.3 mm/sec.

Each strut/wheel assembly will also include a sensor to infer that the wheel is in contact with the terrain. This sensing will be used to allow the vehicle to roll on four wheels (instead of just three, which would be the natural state for a four-wheel vehicle without a passive suspension). This sensing will detect when one of the wheels has encountered an obstacle, allow the vehicle to "hop" with all four wheels pushing so that no significant angular momentum is induced into the body, and allow the Rover to anticipate contact a fraction of a second before landing at the end of a hop.

Hopping is viewed as an important technology experiment for the Rover on the asteroid. Fine positioning of the Rover will be accomplished by normal rolling motion at slow speeds of 1.5 millimeters per second or so. At these speeds it is believed that the gravity force (20 μg nominal) and other forces (e.g. Van der Waal's, electrostatic) will allow the Rover to maintain at least two wheels in contact with the terrain at all times. With contact sensing, the odometry for those wheels which are instantaneously in contact should be quite accurate (~5%). This accurate odometry, together with heading information derived from the sun will allow relatively precise, but slow, motion to selected targets on the surface. For longer range motion, hopping is essential. Hops at up to 20 cm/sec will permit vertical motions of hundreds of meters and horizontal motions up to 1 asteroid radius. Control of the body pose during the hop will allow mosaic imaging during this relatively slow maneuver (e.g. 40 minutes) as well as estimation of the time and place of impact, and the surface topography near the landing site. Control of the body pose and actuation of the struts and wheels just before and during the time of contact will allow impact energy absorption, preventing long bounces (100 meters and 1000 seconds).

The Orbiter-Mounted Rover Equipment (OMRE) will be a rectangular box smaller than 30x30x15cm. The OMRE has the following functions:

1. Thermal control of the Rover during cruise
2. Mounting the Rover to the spacecraft during cruise
3. Ejecting the Rover off the spacecraft at the asteroid
4. Transmitting commands from the Orbiter to the Rover receiving data from the Rover and transmitting it to the Orbiter for re-play to Earth
5. Housing OMRE computer

The MUSES-C spacecraft will provide a few watts during cruise to keep the OMRE above -100C and also above -20C during Rover operations using a Japanese-specified temperature sensor and a resistive heater. At the time of Rover ejection, the Rover will have no power from the Orbiter and will be inactive. The ejection mechanism of the OMRE will have a Rover hold-down which is capable of taking the launch loads, but then with an ejection signal from the Orbiter, can open the latches and release the Rover at about 5 cm/sec.

<u>Panoramic and Near-Imaging Camera (PANIC)</u>

PANIC uses a two- or three-position focus camera with a scannable mirror to allow the Rover to point the camera to areas that are in focus, instead of focusing on areas that happen to be on a fixed camera axis. This approach also enables convenient acquisition of panoramic mosaics, it allows pointing of the camera at the landing site during hops without reposing of the body, and it gives all the benefits of boresighting the spectrometer with the camera without any of the associated complexity. The optical path looks out through an optically-flat window of an appropriate size to allow looking 30 degrees off-axis. The window is on the front of the Rover. Light can be directed via an appropriate mechanism from a wide variety of pointing directions either into the camera or into the IR spectrometer. Two illustrations of PANIC can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

The visible camera is a 512x512 (or fallback 256x256) Active Pixel Sensor (APS) with a 30 mm focal length f/3.2 lens. A dichroic mirror folds the optical path from the nominal horizontal transverse axis to a vertical axis down to the APS detector. A filter wheel with 10 filter positions (4 for engineering, 6 for science) lies between the APS detector package and the dichroic mirror. The filters have not been determined, except that one will possibly be broadband and one may be opaque for measuring dark current. Infrared light passes directly through the dichroic mirror while visible light is reflected into the camera. Each pixel in the APS detector is 11.9 micrometers (microns) square (20 if the 256x256 imager is used). The quantum efficiency, including fill factor, is about 50% and has a well depth of about 250,000 electrons. One or two close-up lenses change the focus from infinity to a point about 20 mm in front of the Rover.

PANIC can take images at about 4 frames per second. PANIC characteristics can be found in Table 11. The baseline design assumes variable lossless, JPEG, or wavelet image compression on the Rover (with possible additional compression on the OMRE). For example, if the telemetry rate is 38.4 kbps, it take about 3.5 minutes to uplink the full memory to the spacecraft.

Table 11. PANIC Characteristics

Parameter	Value
Sensor type	Silicon, Active Pixel Sensor, block addressable, on-board digitizer
Array size	512 x 512
Detector pitch	11.9 microns/ pixel (square)
Useful digital bits/ pixel	9 - 10
Maximum read rate	1 Mpixels/ sec
Fill factor	27%
Well depth	250,000 electrons
Read noise at 20 C	50 electrons
Wavelength of maximum QE	600 nm
Spectral range (QE>3%)	450 - 950 nm
Dark current at 20 C	2000 electrons/ sec

Near-Infrared Spectrometer (NIS)

The Near-IR Spectrometer (NIS) planned for the MUSES-C Rover is adapted from the design of a commercial field-portable spectrometer. The infrared spectrometer consists of an aspheric 18.4 mm F3.2 objective lens which focuses light from scene via the gimbaled flat mirror onto a slit via a gold-coated fold mirror. A dichroic reflects the visible light onto the camera and passes the IR light through to a 1 mm x 200 micron entrance slit for the spectrometer. The light, which passes through the slit, illuminates a custom concave holographic diffraction grating.

The light which diffracts off the grating impinges on a detector, such as the 256x1 Indium Gallium Arsenide (InGaAs) detector array. This would make a single octave spectrometer covering the spectral range of 0.9 to 1.7 microns of wavelength, with a spectral resolution of about 5 nanometers. The pitch of this array is 50 microns per pixel, so the input slit will be about 50 microns wide.

The slit, grating, and IR detector array will all be in a sealed box which has black flocking material for light absorption and several light baffles. The slit will be slightly offset from the beltline symmetry plane of the grating, and the detector a corresponding amount on the other side of that plane in order to control stray light.

The grating has 400 lines per mm, and is optimized for performance in the first order such that the first order is used with the detector for the band from 0.9 to 1.7 microns. A similar grating incorporated into the first prototype Rover has a measured grating efficiency of 31% in first order and 10%. The detectors have internal two-stage thermoelectric coolers which can lower the detector temperature by about 75K when 1.3W of power is available. NIS characteristics are shown in Table 12.

Table 12. Near-Infrared Spectrometer (NIS) Characteristics

Quantity	**Expected Performance**
Wavelength Range	0.9 - 1.7 microns
Detector	InGaAs, long-wavelength enhanced
Pixel format	256 x 1 linear array
Pixel size	1 mm x 50 microns
Readout noise	200 electrons/ root (scan)
Well depth	5 million electrons
Dark current	Doubles every 7 - 10K
Gain	300 nanovolts/ electron
Grating	Concave Holographic
F number	5
Radius of curvature	100 mm
Input slit	1 mm x 50 microns
Foreoptics	Aspheric single element
Focal length	18.4 mm
F number	F4.3
Focus distance	50 mm
Active Illuminator	Tungsten filament 0.2 x 1 mm
Power	0 - 300 mW variable in 255 voltage steps
Temperature	Ambient - 2800K
Focus optics	4.5 mm F1 aspheric
Focus distance	50 mm
Readout electronics	
Digitization	12 bits (0 - 5 V)
Readout rate	200 K samples/ sec
Readout style	Double integrated sampling (requires 2 samples/ pixel)

Alpha X-ray Spectrometer (AXS)

The (Alpha X-ray Spectrometer) AXS measures the chemical composition of the asteroid. Especially important is the determination of light elements (H, C, N, O) because of their important role in organic matter. A goal is to obtain the complete elemental composition of selected areas of the surface of the asteroid and this will be achieved by a derivative of the Alpha Proton X-ray Spectrometer that was used on the Mars Pathfinder mission. The AXS specifications are given in Table 13.

Table 13. AXS Specifications

Parameter	Specification
Mass	130 grams
Power	< 200 mW
Integration time	2 - 10 hours
Volume	75 cm^3
Alpha radioactive source	50 milliCuries of Curium-244
Energy resolution	160 - 190 eV

The AXS for MUSES-C is a much smaller instrument than the Pathfinder APXS. The sensor head was reduced substantially in size in order to fit inside the available space of the Rover. Additional reduction in size and power was achieved by:

Hybridizing the main electronics
Eliminating the proton mode of the Pathfinder APXS
Utilizing some of the Rover resources (mainly microcontroller, memory and ADC).

The AXS provides composition information and ground truth for remote measurements. The AXS is really two instruments in one package:

Alpha mode - elastic scattering
X-ray mode - excitation of the atomic structure by alphas and subsequent x-ray emissions

The alpha mode, besides determining very accurately the light elements carbon, nitrogen, oxygen, etc., will also provide information for absolute concentration calibrations. The alpha mode will be identical to the Pathfinder APXS alpha mode. A typical alpha spectrum from a TRATIV 1 rock that is almost pure carbon carbonate can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

The X-ray mode of the AXS is also identical to the Pathfinder APXS X-ray mode and it will provide the bulk of the information about the heavier elements of the asteroid's surface. A typical X-ray spectrum of Martial soil site obtained by Pathfinder APXS can be found at Internet URL <http://muses.larc.nasa.gov/muses>. It is expected that the energy resolution of the AXS X-ray detector will be somewhat better than the Pathfinder APXS.

The AXS uses, for both alpha and X-ray modes, about 20 milliCuries of Cm-244 which is a radioactive isotope that emits 5.8 keV monochromatic alpha particles. The instrument is able to measure all elements present in the sample (except hydrogen and helium) above 0.1 % level for major elements and down to several hundreds ppm for many minor and trace elements.

A diagram of the sensor head for the MUSES-C AXS showing the geometrical relationship of detectors, alpha radioactive sources, and collimator can be found at Internet URL <http://muses.larc.nasa.gov/muses>. The sensor head, approximately one cubic inch in size, will be placed inside on one end of the Rover, and it will be deployed to the surface sample for analysis by manipulating the Rover box until a contact with the surface has been made.

1.5 Returned Sample

A NASA scientist will be selected to join the Japanese sample science team in examining (in Japan) the returned sample for the first year after recovery.

1.5.1 Measurement Objectives and Experimental Approach

The measurement objectives and associated techniques for the returned sample are listed in Table 14.

Table 14. Asteroid Sample Measurement Objectives and Techniques

Analytical Technique	Techniques	Objective
Petrography	Optical microscopy Electron microscopy	Sequence of mineral formation and alteration Regolith processes
Mineralogy, elemental abundances	Reflectance spectroscopy X-ray diffraction X-ray fluorescence TEM	Composition Thermal and aqueous alteration Relationship to planets, comets, meteorites
Water, organics	Reflectance, emittance, Raman spectroscopy	Presence and abundance of water and organics History of volatile mobility
Major/ trace elements, stable isotopes	Electron probe Instrumental neutron activation Solid/ ion mass spectroscopy (bulk)	Chemical processes Thermal evolution Relationship to planets, comets, meteorites Origin of the elements
Detailed organic chemistry	CHONS analysis GC/MS, LC/MS analysis Laser desorption TOF mass spectroscopy	Organic chemical evolution Relationship to comets and meteorites
Noble gases	Solid/ ion mass spectroscopy	Relationship to comets and meteorites Relationship to terrestrial volatiles Regolith processes Exposure history

1.5.2 Description of Facilities/ Arrangements

Fundamental analysis and curation activities will be performed in an analysis facility in Japan. In the facility, cooled and evacuated chambers are installed for preservation and preparation of the samples. An optical microscope and a SEM are attached to the chamber, and by using manipulators, it is possible to perform fundamental analysis of the sample without any appreciable contamination. After this analysis, the suitable samples will be selected for use in each program. The facility has clean rooms for organic and inorganic analysis and contains analytical devices (IR-spectrometer, Raman-spectrometer, XRF spectrometer, INAA apparatus, X-ray diffractometer, etc.) Some of the advanced studies shown in Table 14 will be carried out in various universities and institutes in Japan.

2. MISSION AND SCIENCE OPERATIONS

2.1 Overview

2.2 Role of MUSES-C Joint Science Team in Science Operations

The science team is expected to assist the MUSES-C Project teams at ISAS and JPL with mission planning activities. Such activities may include operations scenario planning and negotiation, prelaunch and postlaunch calibration and test plans, and design reviews. The Project Manager of MUSES-C has the final decision-making authority in any deliberations which may jeopardize the spacecraft or the mission. Likewise, the MUSES-C NASA Project Manager has the final decision-making authority on actions which may affect the health of the Rover or the success of the MUSES-C Rover mission.

2.3 Cruise Science/Calibrations

AMICA plans to do calibrations using standard star sets during cruise, in addition to flat-field calibrations via a strut-mounted calibration lamp. There are no LIDAR activities planned during cruise, NIRS plans to do an in-flight calibration by observing some bright stars. XRS is planning cruise calibrations for its main sensor and sun sensor. There are no cruise calibrations planned for the Rover instruments since they will not receive power.

2.4 MUSES-C Rendezvous Operations

2.4.1 Spacecraft Orientation

During the mapping phase at the asteroid, the spacecraft will be oriented so that its solar panels face the Sun. The spacecraft will be 26 degrees off the Sun-asteroid line at arrival (about 9 degrees at departure) to avoid high temperatures radiating from the asteroid surface. The instruments will be canted 0 degrees from the spacecraft z-axis to still be useful in the far-approach phase. As the spacecraft descends, it will slowly rotate such that the feedhorn of the sample collection device is nadir-pointed at the asteroid for free-fall to the surface. An illustration of the spacecraft orientation during descent can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

2.4.2 Data Recording and Playback Capabilities

The spacecraft has enough power to operate all instruments and store data simultaneously. During data downlink periods, the instruments may simultaneously operate and record new data. One 256 Mb solid state data recorder randomly accessible and capable of packet telemetry data will be available for storing science data during times when data downlink is not possible. The recorder can simultaneously record and playback data.

At Nereus, the spacecraft telemetry system will support a discretely-alterable downlink data rate up to 16 kbps to the 64 m Usuda station. One Usuda pass per day is assumed for planning purposes beginning 7 days before Nereus rendezvous and ending 7 days after the spacecraft leaves Nereus. This plan is not a commitment and is subject to change. An example of a sample, one-hour daily data gathering and allocation strategy amongst the instruments can be found in Table 15.

Table 15. Example Daily MUSES-C Instrument Data Rates (Preliminary)

System	Data Rate (kbps)
AMICA	52
NIRS	6
XRS	0.1
Housekeeping	1 – 4
AOCS	1
Others	1
OMRE	8 Mbits per day

2.4.3 Science Operations

The following sections outline the MUSES-C science operations scenarios. Please note that these are preliminary and will change as the mission design progresses.

Strawman Science Scenario

A detailed science scenario will be worked out with the aid of the scientists selected as a result of this AO process. However, a rough strawman science scenario is offered below for preliminary planning purposes. Because of its design, the spacecraft will spend most of its time "hovering" above the asteroid in a nearly fixed position on the sunward side of the asteroid. As a result, observations will be made as the asteroid rotates beneath the spacecraft. As the spin pole orientation of the asteroid is not yet known, it is unclear as to what portion of the asteroid's surface will be observable by the spacecraft's instruments. During certain mission phases, the spacecraft will be autonomously brought down to very low altitudes including "touchdowns" for the sample collection phases.

From a range of about 100,000 km to about 50 km, a variety of observations will be made to characterize the physical nature of the target asteroid. The AMICA will be used for a satellite search and to characterize and map the asteroid's surface morphology. Preliminary estimates will be made for the asteroid's physical characteristics including its size, shape, spin state, and volume. In-situ disk resolved multicolor photometry will be compared with similar efforts from the ground. A series of observations are planned to establish a polarization vs. phase angle curve. As the spacecraft's altitude is lowered from 50 km to distances of 20 km and less, refinements will be made to the asteroid's physical characteristics and the asteroid's surface map.

Between the ranges of 50 km and 50 m, the LIDAR will be used to map the surface roughness to a maximum resolution of about 1 m.   LIDAR data will also be used to provide information on the detailed shape of the asteroid and, using a series of free-fall spacecraft maneuvers, the LIDAR data will be used to determine the asteroid's mass to the 1% level.

The Near-IR Spectrometer (NIRS) will characterize the mineralogic composition of the asteroid's illuminated surface and provide evidence for the rock types present on the surface at scales as small as about 20 m when the Orbiter is located a few km off the surface.

The X-Ray Spectrometer (XRS) will require fairly lengthy integration times to determine the asteroid elemental composition. The XRS will operate most efficiently when the spacecraft is below 11 km, a distance at which the asteroid fills the instrument's field of view.

Sample Collection

The MUSES-C science instruments are also critical for navigation during the asteroid descent phase in preparation for touchdown. An illustration of a sample descent sequence can be found at Internet URL <http://muses.larc.nasa.gov/muses> and describes when the Orbiter instruments will be used during descent as a function of altitude.

At an altitude of about 200 m, the Orbiter will drop a target marker onto the asteroid. The wide-angle camera (ONC-W) will be used to track the target plate once it settles. At an altitude of 20 m, the spacecraft will eliminate vertical velocity and hover in order to drop the Rover. It is important not to use thrusters during this time in order to allow the Rover to fall a safe distance away and also to avoid pushing the target plate off the asteroid.

The spacecraft will free fall from 20 m onto the surface of the asteroid. This phase is totally autonomous. ONC-W will be used for target-plate tracking until about 2 m from the asteroid surface. At an altitude of about 50 m, the LIDAR will not be used anymore, and a laser range finder and fan-beam sensor will be used for altitude sensing. At touchdown, the sample collection will occur as previously described. The sample catcher has three sample collection tubes inside. Each tube will be vacuum-sealed after the sample has been inserted.

The investigator selected through this AO will be part of the sample site selection. Up to three different sites will be chosen based on asteroid mapping after Nereus arrival.

2.4.4 Rover Operations

Once the Rover settles on the asteroid surface, its first job will be to meet its mission success criteria. The Rover will take an image, move, and take another image, followed by an IR spectra and an AXS measurement. The data collected will be transmitted to the OMRE on the Orbiter for downlink before nightfall during the first day.

Rover Orientation

The Rover antenna is mounted on one face (designated the top face). During data transmission, the top face will be pointed toward the OMRE. All faces of the Rover have solar panels so that the Rover will always have enough power to right itself if it flips over in microgravity. The Rover can be oriented in any position so that the instruments can be pointed in any orientation. However, due to the low overall power budget, instruments must be used one at a time.

Data Recording and Playback Capability

The Rover does not have enough power to operate all instruments and store data simultaneously. During data downlink periods, the instruments may not simultaneously operate and record new data. For science data storage, 0.5 Mbytes will be available. Essentially all data must be transmitted daily to the spacecraft, otherwise it will be lost when the Rover loses power during the asteroid night (only a few Kbytes of science data can be stored in non-volatile RAM). The Rover can transmit data at 38.4 kbps. This data rate is fixed and will not change with Orbiter distance. The Orbiter will downlink 8 Mbits of Rover data from the OMRE to Earth every 24 hour period. The Rover can store up to 4 Mbits of science per day. Assuming a compression rate of 10:1, the Rover can collect 40 Mbits of data each day for transfer to the spacecraft. However, this is for example only; the actual science compression rate will be negotiated with the science team members once they are selected. The images which the Rover needs for navigation may have a different compression rate than the science images.

One uplink pass per day from the Rover to the spacecraft is assumed for planning purposes beginning on the day of Rover release at Nereus and ending after the spacecraft leaves the asteroid. This plan is not a commitment and is subject to change. An example of a daily data gathering and allocation strategy amongst the instruments can be found at Internet URL <http://muses.larc.nasa.gov/muses>.

Rover Science Operations

Once the mission success criteria are met, typical Rover operations will begin. Daily operations will include panoramic and microscopic surface imaging, IR spectra, and AXS measurements from various surface sites of interest. Since the rotation rate of Nereus is about 15 hours, a conservative asteroid daytime period lasts around 7 hours. During this time, observations will be sequenced according to science criteria and engineering constraints.

Transmission of 8 Mb of data to the OMRE, for example, will take about 3.5 minutes, leaving almost the entire 7 hours of time to gather data and move about the asteroid. Since the Rover can only move 1.5 mm/ sec without losing contact with the asteroid surface, the Rover can move 5.4 m per hour (assuming no major obstacles). Investigators will have to trade off distance vs. observation time. In addition, depending on the landing site latitude and rotation axis direction, daily temperature variations will have to be taken into account when sequencing daily investigations. For instance, it is likely that the IR point spectrometer is best used early or late in the asteroid day, which may compete with AXS measurement time. Since there is no battery on the Rover, there is no power available to the instruments (or Rover) during the asteroid night.

Additional experimental goals include:

Attempting to image a crater made by the sample collection device in order to gain information on stratigraphy
Hopping 10 - 100 m in low-gravity in order to extend daily mission operations and data gathering opportunities (by staying in the Sun longer)
Optical communications with the OMRE and the Earth
Any experiments which may further our understanding of soil mechanics or mobility in a microgravity environment.

2.5 Returned Sample

Once the sample capsule returns to Earth, it will be returned to ISAS. The samples in the capsule will be transferred to the analysis facility in a cooled vacuum state. The samples will be taken out of the preservation cabinet in the contamination-controlled facility. At this time, the samples will be weighed, and the shape of the fragments will be observed and their photographs taken, and the outgas components will be analyzed. Then the samples will be separated for primary analysis, the secondary analysis, and the preservation for the future use. The latter two samples will be preserved in a refrigerated and evacuated state. The sample for the primary analysis will be studied according to the process given in Table 14. Nondestructive analysis will be made first, followed by destructive analysis.

The purpose of the primary analysis is to determine the fundamental properties (such as density), make a fundamental description of the samples at the mineral level, and determine the elemental and isotopic bulk components and organic components. An NRA will be released for the secondary analysis (more advanced than the primary analysis) after the announcement of the results from the primary analysis.